JUN 07 2005

REPORT DOCUMENTATION PAGE	Form Approved OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	2.Jun.05	MAJOR REPORT

4. TITLE AND SUBTITLE
A BETTER NOISE COMPLIANCE METHOD AND VALIDATION OF MINE NOISE DOSIMETRY DATA.

5. FUNDING NUMBERS

6. AUTHOR(S)
MAJ SLAGLEY JEREMY M

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
WEST VIRGINIA UNIVERSITY

8. PERFORMING ORGANIZATION REPORT NUMBER
CI04-1106

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
THE DEPARTMENT OF THE AIR FORCE
AFIT/CIA, BLDG 125
2950 P STREET
WPAFB OH 45433

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION AVAILABILITY STATEMENT
Unlimited distribution
In Accordance With AFI 35-205/AFIT Sup 1

DISTRIBUTION STATEMENT A
Approved for Public Release
Distribution Unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

20050615 054

14. SUBJECT TERMS	15. NUMBER OF PAGES
	17
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT

A BETTER NOISE COMPLIANCE METHOD AND VALIDATION OF MINE NOISE DOSIMETRY DATA

Jeremy M. Slagley,[1,2] *Doctoral Student*
Steven E. Guffey,[2] *Associate Professor*
[1] Air Force Institute of Technology
[2] Department of Industrial and Management Systems Engineering

West Virginia University, Morgantown, WV, USA

ABSTRACT

Given the costs of Noise-Induced Hearing Loss in mining, and MSHA's proactive attention given to all mines, an average exposure determination may be more appropriate for compliance decisions than the current shift-by-shift basis. If dose averages are used, database errors must be minimized.

Errors in dosimetry data can be detected by a variety of means, including: 1) from an understanding of the mathematics relating action level doses to permissible exposure level doses, and 2) corroboration with previous or concurrent survey information. A comparison of the two schemes is presented, and several simple methods for validating dosimetry data are explained.

INTRODUCTION

According to 30 CFR § 62.130, MSHA must require mine operators to:

> "assure that no miner is exposed during any work shift to noise that exceeds the permissible exposure level. If during any work shift a miner's noise exposure exceeds the permissible exposure level, the mine operator must use all feasible engineering and administrative controls to reduce the miner's noise exposure to the permissible exposure level, and enroll the miner in a hearing conservation program ..."

The permissible exposure level is a noise exposure dose of 100% in one "shift" of exposure. Given that the goal of the standard is to prevent hearing loss in miners and that hearing loss occurs from years of high exposures, it is inconsistent to enforce dose limits on a shift-by-shift basis. As will be shown, this regulatory emphasis on shift exposures rather than long-term average exposures appears occasionally to produce citations in cases where annual exposures probably average below 100%. As will also be shown, this policy also sets up the situation where operators with annual exposures below 90 dBA are likely to be cited eventually, with the probability of an eventual citation being determined, in part, by the frequency of noise dosimeter surveys done by MSHA.

The "permissible" noise dose is 100%, but the MSHA manual for inspectors instructs them to cite only for shift noise doses exceeding 132%, which is equivalent to an 8-hr time weighted averaged (TWA-hr) of 92 dBA. This higher threshold presumably was adopted for two reasons: 1) as in other non-felony legal actions, MSHA must demonstrate a "preponderance of evidence" to substantiate their charges of violations of the standard, and 2) MSHA apparently believes that 2 dBA represents the "error" of their dosimeters. A lawyer might argue that preponderance of evidence requires only 50.1% probability and that this interpretation effectively increases the permissible dose to 132%. On the other hand the sampling error is much larger than 2 dBA.

As will be demonstrated, due to the variability of doses, citing based on a single high shift tends to reduce the effective permissible dose to less than 100%. On the other hand, setting the effective standard to 132% increases the allowed permissible dose. As will be shown, the net effect of these offsetting factors will vary from one mine to another.

In enforcing the MSHA has been sampling long-wall mining noise exposures using dosimeters for decades. The MSHA noise standard allows up to 100% dose when determining if engineering changes are required and 50% when determining if a hearing conservation program is required. It is current MSHA policy to cite for violations of the MSHA noise standard if any miner's exposure on a given day exceeds a 132% dose. This is mathematically equivalent to OSHA's policy of citing based on an 8-hour time-weighted average (TWA-8hr) of 92 dBA.

Neither policy is mandated by legislation. Both policies are followed for reasons of administrative convenience. If the dose for citation were 101%, for example, a mine could be in compliance one day and out the next due to random variations in noise exposures.

For the ranges of noise exposure in mining, hearing loss cannot occur in one day. It takes years of chronic exposures to doses above 50% to produce substantial effects. Hence, the average annual dose would be strongly related to hearing loss; the average for one day is only relevant if that day is representative of the year. The yearly average exposure is relevant and one-day or one-week averages are not. The policy of citing based on one day's high exposure is crucial to OSHA given that there are not enough OSHA inspectors to spend more than one day per operation per decade

Both MSHA inspectors and mine operators typically place dosimeters on miners at the beginning of a shift prior to entering the mine and remove them after or just before they exit. This procedure minimizes the time spent on noise measurements, allowing more time for other duties while capturing all of the exposure time for each miner that is sampled.

The disadvantages of this approach to full-shift sampling are twofold. First, the decision scheme was designed for an inspection agency with insufficient resources to monitor all work sites (OSHA) and therefore places the burden of proof on the inspection agency, making an inequitable sharing of risk between the employer and employee. Secondly, there is a lack of detailed information about the exposures: 1) unless data-logging dosimeters are used, there are no data showing actual noise levels, 2) there is no record of downtime and other events that would affect exposure, including issues useful when considering engineering and administrative controls, and 3) the noise dose includes long periods of non-exposure (e.g., entering and exiting the mine), obscuring possible changes to noise levels during work.

Another issue is data integrity. Unless data-logging dosimeters are used, the only information about the subject's exposure is the percent dose (Dose). There is no way to determine from the instrument reading if the miner's activities were representative of his normal work shifts or if the dosimeter was abused or left in a quiet place for a time. Finally, if the %Dose is written down incorrectly before deleting it from the dosimeter there may be no way to detect the error unless there is redundant information that can be used to challenge the validity of the reported reading.

As will be discussed, an examination of MSHA data showed that at least 2.3% of values were clearly incorrect. An unknown number of additional errors may be present but undetectable without additional information. A related issue is consistency of findings: there have been few published comparisons of data collected by MSHA and mine operators.

This publication compares current and proposed compliance determination schemes for noise hazards. Then the authors compare MSHA and operator dosimetry data for the same mines and discuss means to detect invalid measurements.

BACKGROUND

MSHA Noise Standards

When MSHA finds the dose to be above 132%, it issues a citation for noise exposure if the mine has no previous citation. If the mine already has been cited, MSHA may extend the current citation or pursue a P code if all feasible measures have been exhausted. Dose is computed as the summation of actual times of exposure divided by the allowed time at that level of noise:

$$Dose = 100\% \sum_{i=1}^{n} \frac{T_i}{480x2^{-\left(\frac{SPL_i - 90}{5}\right)}} \quad \text{..} \quad 1$$

Where: T_i = duration at SPL_i in minutes

SPL_i = sound pressure level, i, in dBA

n = number of levels measured

Table 1. MSHA Standards

Standard	Criteria, dBA
AL	80-130
PEL	90-140
Max	115
Dual hearing protectors	105

In determining dose, not all sound levels are counted. As shown in Table 1, MSHA includes all noise levels from 80 to 130 dBA when determining its "Action Level" (AL). MSHA includes 90 to 140 dBA in determining compliance with its "Permissible Exposure Limit" (PEL). Hence:

$$Dose_{AL} = 100\% \sum_{i=1}^{n} \frac{T_i}{480x2^{-\left(\frac{SPL_i - 90}{5}\right)}} \quad \text{..} \quad 2$$

Where: SPL_i = sound pressure level, i, for the range 80-130 dBA

$$Dose_{PEL} = 100\% \sum_{i=1}^{n} \frac{T_i}{480x2^{-\left(\frac{SPL_i - 90}{5}\right)}} \quad \text{..} \quad 3$$

Where: SPL_i = sound pressure level, i, for the range 90-140 dBA

This is widely recognized as a method of putting the burden of proof on MSHA to show that there is clearly an overexposure before citing a mine operator. Only SPLs above 90 dBA are included in the dose calculations, and the 132% citation threshold takes into account the ±2dB precision of type II noise meters. This decision logic mirrors that of the Occupational Safety and Health Administration (OSHA). It may not fit mining as well as it does general industry.

Generally, OSHA inspectors will never visit any given work site unless there is a problem, complaint, or a focus on that industry. It would be extremely difficult for OSHA to maintain a representative average of exposure data for the many similar exposure groups within each work site in the country. OSHA must focus their inspections to cite those employers who are clearly overexposing their employees based on a single site visit. Given the difficulty in making an exposure assessment decision on a single measurement, it is reasonable to give the benefit of the doubt to the employer.

However, this is an inequitable distribution of risk between the employers and employees. In effect, after the PELs are established, the exposure situation has still got to be much worse than the PEL in order to cite. Actually, with the ±2dB imprecision of type II noise meters, it is just as likely that the 100% dose measurement was low, and the actual value was 132%, or that the 76% dose measurement was actually 100%. Further, the state of the electronics involved in noise measurement is far superior to that at the time of the promulgation of the first safety and health regulations. The meters tend to drift much less, and since MSHA performs calibration checks before and after each survey, and has the meters calibrated annually at the Pittsburgh Research Laboratory, there is less risk of imprecision now.

Also, because of the inherent health and safety risks of mining, there are more inspectors and more frequent inspections from MSHA than in general industry from OSHA. In fact, whereas OSHA may never visit any given work site, MSHA will definitely visit every mine—and frequently. Therefore it may be more reasonable and a more equitable sharing of risk for MSHA to cite based on average exposure readings. Given the benefit of accuracy and risk equity, it would then be very important to have methods to ensure accuracy of the exposure data within the MSHA noise dosimetry database.

Validation of Dosimetry Data

There are several ways to validate dosimetry data and detect errors, including: 1) from an understanding of the mathematics relating action level dose to permissible exposure level dose, and 2) corroboration with previous or concurrent survey information. Several simple methods for validating dosimetry data are explained.

METHODS

This paper uses nation-wide MSHA underground longwall mining noise dosimetry data (n=577) in comparing compliance decision schemes. Longwall coal mining dosimetry data collected by mine operators in seven different mines in Appalachia (n = 57) compared to MSHA dosimetry data collected in the same mines (n = 98), or the same regions (n=198) was used for exploring data validation techniques. The four longwall crew occupations included were the headgate operator, jacksetter, and the head and tail gate shearer operators. The mine operators' data was part of a carefully-conducted mine noise study with task analysis performed in 2004. The MSHA data was taken from the publicly available MSHA noise dosimetry database from 2000-2004. (MSHA, 2004) All data was collected following the guidelines in MSHA's Coal Mine Health Inspection Procedures Handbook. (MSHA, 2001) Dosimeters were set to the parameters in Table 2.

Table 2. MSHA dosimeter settings

Setting	Criteria Level	Exchange Rate	Threshold
$Dose_{PEL}$	90	5	90
$Dose_{AL}$	90	5	80

Simple data manipulations and charts were performed with Microsoft Excel© software (Microsoft Corp., Seattle, WA), while statistical analysis was performed with JMP Intro© software (SAS Institute, Carey, NC).

MSHA Noise Compliance Decision Schemes

In order to understand the underlying noise data distribution, the $Dose_{AL}$ was converted to equivalent sound pressure level (L_{eq}), which follows a normal distribution. The standard deviation of the actual mine noise data was then used to model several data sets with different assumed true means. These data sets were then analyzed to compare the current MSHA compliance decision scheme vs. a scheme using the average dose over several visits.

Validation of Dosimetry Data

To assure the validity of dosimeter data, there are several strategies that can be helpful. The best strategy is to collect corroborating information at the time of the sampling, but analysis of the collected data can also be useful. Several possibilities are considered in the following sections.

Corroborating With Redundant AL and PEL Dose Readouts

MSHA requires that both AL and PEL dose readings be taken simultaneously. This technique captures those doses that fall below the PEL but would still break the action level and require a hearing conservation program. Fortunately, many dosimeters can report both $Dose_{AL}$ and $Dose_{PEL}$ simultaneously. This dual data can also provide a possible check for transcription errors of either one. The difference between $Dose_{AL}$ and $Dose_{PEL}$ is not always trivial. Except in the rare instances where exposures exceed 130 dBA for some period of time, the difference is entirely due to the period of time that noise levels are between 80 and 90 dBA. As can be demonstrated mathematically, the maximum possible difference for an 8-hour work shift is 100%. That difference would occur when all 480 minutes of exposure were at 89.99 dBA (i.e., just below 90 dBA). For non-8-hour shifts, the maximum difference is proportional to the shift duration, assuming the entire shift is sampled. For example, for a 10-hour shift in which every minute was at 89.99 dBA, the difference would be 125%. Likewise, if only 4-hours were at 89.99 dBA, the maximum difference would be 50%.

The maximum contribution of the 85-90 dBA noise is strongly affected by another fact: real noise exposures vary from minute-to-minute. Hence, it is extremely unlikely that a miner will be exposed to 89.99 dBA for hours at a time. Even a small amount of variability would have a major effect. For example, if the noise exposure averaged 89.99 dBA but had a standard deviation of 0.1 dBA, almost half of the exposure would be above 90 dBA and would not contribute to the difference between AL and PEL. Thus the maximum difference between AL and PEL would be just over 50% for an 8-hour exposure with an average noise level of 89.99 dBA.

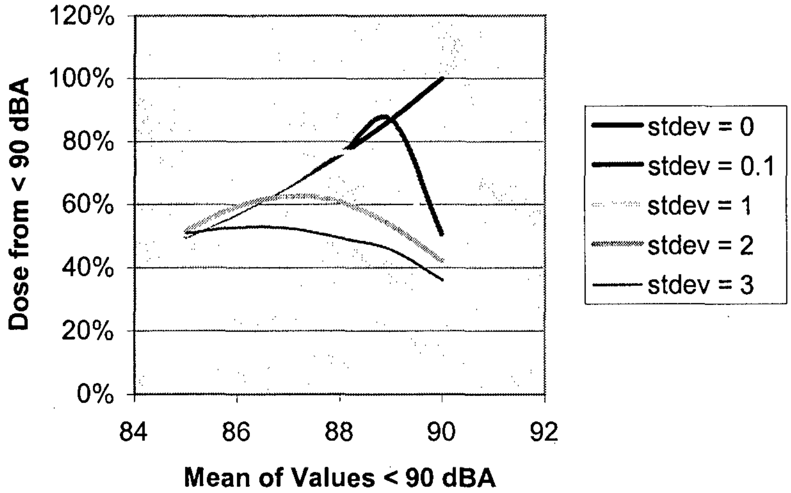

Figure 1. Maximum Difference in AL and PEL for an 8-hour exposure

It is far more likely that actual standard deviations for the most highly exposed occupations will generally be in the range of 2 to 5 dBA. The maximum possible difference between $Dose_{AL}$ and $Dose_{PEL}$ values is strongly affected by those levels of variability. As shown in Figure 1, which was developed using Monte-Carlo methods, the maximum contribution from noise exposures below 90 dBA will almost certainly be less than 30% even if the exposure covers a full 8-hours. If the time spent in the 85-90 dBA range is less than 8 hours per shift, then the maximum possible contribution is proportionately lower. The higher the dose, the less time was probably spent in the 85-90 dBA range and the more was spent at higher than 90 dBA. Hence, the maximum likely difference between $Dose_{AL}$ and $Dose_{PEL}$ declines with increasing dose for a given shift length. This can be simulated using two assumed distributions, one with a mean below 90 dBA and the other centered above 90 dBA. Therefore, when recording dose values from a dosimeter, if the $Dose_{PEL}$ exceeds $Dose_{AL}$, there is an error. If the $Dose_{AL}$ exceeds $Dose_{PEL}$ by more than 50%, there may be an error unless it is know that the miner had little exposure to noise sources capable of producing noise above 90 dBA. Further, to avoid transcription error, the dosimeter data should be downloaded or printed directly to have a verifiable copy of the data before deleting.

Corroborating With Concurrent Survey Information

Particularly useful corroborating data are sound level meter (SLM) measurements taken at the ears of the miners wearing the dosimeters. Indeed, if one takes at least 30 readings at random times over the shift, there should be no consistent difference between the SLM survey and the dosimeter results. However, even a few measurements can be useful, especially when combined with other information. It is particularly helpful to know the duration of each noisy task and the noise levels associated with each task. If the noise level is relatively constant during the task, then even a few measurements can accurately represent the task. For example, if a miner normally works roughly 6 hours per 8-hr shift at a task that measures 93-97 dBA and has negligible exposures the rest of the shift, one would be rightfully concerned if the cumulative dose over the shift was much less than 110% or more than about 160%. Such task analyses are extremely useful.

Corroborating with Production Data

Production records and knowledge of conditions allow one to narrow the range for comparison. For example, if the production on the day of the survey were substantially lower than other days, one would not be surprised to find that the dose was on the low end of the range. If the work encounters more rock in the seam than in the past, one would expect higher doses.

Corroborating with Previous Surveys of the Same Exposures

Other corroborating information allows comparison to previous surveys. A record of previous survey results with notations about whether the shift was perceived to be routine can be very helpful. If the miner believes his work day also "routine," one would be surprised if his dose for that shift fell outside of the range measured on other routine days. On the other hand, if engineering controls have been installed since the last survey, one might expect some reduction and be unpleasantly surprised if the expectations proved over-optimistic.

Corroborating with Surveys in Other Mines

If no previous surveys have been done, then the next best comparison is to the experience of other mines for the same tasks. Of course, there are large differences from one mine to another, but one can make rough judgments about where in the range this mine should fall. For example, if this mine has much longer than usual transit times to work sites, then one would expect to fall somewhat lower in the range if the mantrip exposures are not above 90 dBA. Likewise, if the production rate is much lower for one mine than another with similar equipment and seams, one would expect lower doses.

RESULTS

MSHA Noise Compliance Decision Schemes

In order to show the current state of affairs regarding MSHA's citation decision scheme, the equivalent sound pressure levels (L_{eq}) from the daily doses in the MSHA database were calculated. The L_{eq} values were normally distributed with mean = 90.6 dBA and standard deviation = 3.7 dBA. Then, assuming the same standard deviation but different true means of a given mine's exposure distribution, the negative binomial cumulative distribution returned the probability that a mine will be cited within a given number of MSHA visits. Figure 2 indicates that a mine with a true mean L_{eq} of 85 dBA still has greater than a 10% chance of receiving a citation by their 3rd MSHA visit, even though only 0.29% of their exposures actually exceed the 92 dBA citation threshold. For a mine with a true mean L_{eq} of 90 dBA (acceptable exposures), they have more than a 90% chance of citation by their 6th MSHA visit, even though they are actually in compliance. In effect, if you keep looking, you will eventually find an exceedance.

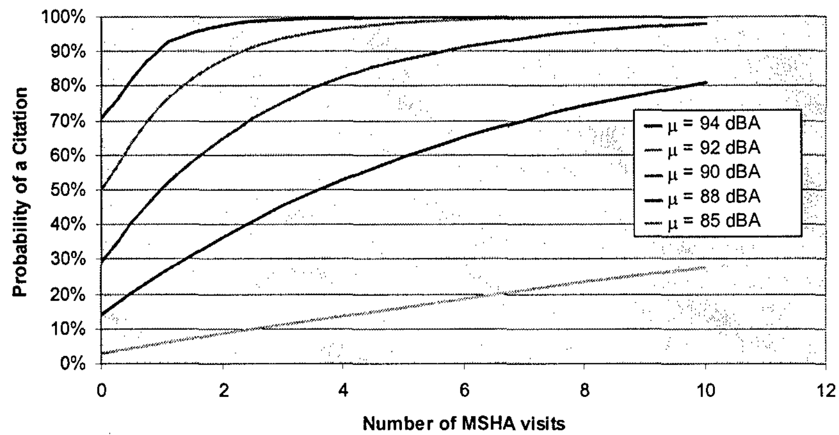

Figure 2. Probability of citation by # of MSHA visits for given exposure distributions

If it can be agreed that the mean exposure is a better assessment of risk for the chronic disease of NIHL, then a comparison of the MSHA scheme vs. average dose is appropriate. By analyzing the MSHA database, one can find instances of mines with average exposures above 100% dose that did not get cited, as well as mines with average exposures below 100% that did get cited. Table 3 shows that for the listed occupations, the first two mines had averages below 100% but were cited on their last visit. Mines three and four had averages above 100% and were cited appropriately. Mines five and six had average doses above 100%, but were never cited.

Table 3. MSHA citation scheme success and failure

Mine	Occupation	n	Average	Citation on visit #
1	Jacksetter	9	97.2%	9
2	TG shearer	4	99.5%	4
3	Stageloader	5	108.0%	3
4	Stageloader	5	102.6%	3
5	TG shearer	5	109.0%	never
6	Jacksetter	5	107.4%	never

Average exposure could be a much better method of assessing the occupational risk to miners. It also provides for a more equitable sharing of risk, and a better representation of the exposure situation. A limitation would be that several readings should be taken before an initial classification could be made. However, the current decision scheme could be used until at least 3-5 readings were taken from an occupational group at a mine. Other governmental organizations use this type of exposure assessment scheme to determine average exposure. (USAF, 1994)

Validation of Dosimetry Data

Corroborating With Redundant AL and PEL Dose Readouts

A benefit of collecting simultaneous $Dose_{AL}$ and $Dose_{PEL}$ data with the same instrument on the same miner at the same time is that the data should be highly correlated. In effect, since all the human and sampling error associated with environmental data are the same for those two data points, the correlation of the data should be error-free. Any extraneous error in the correlation indicates incorrect data transcription.

MSHA $Dose_{AL}$ and $Dose_{PEL}$ data are correlated in Figure 3. Any data above the red line with slope = 1 are impossible ($Dose_{PEL}$ cannot be larger than $Dose_{AL}$). Unless there is a written or computer record that shows the original data properly recorded, the data must be abandoned.

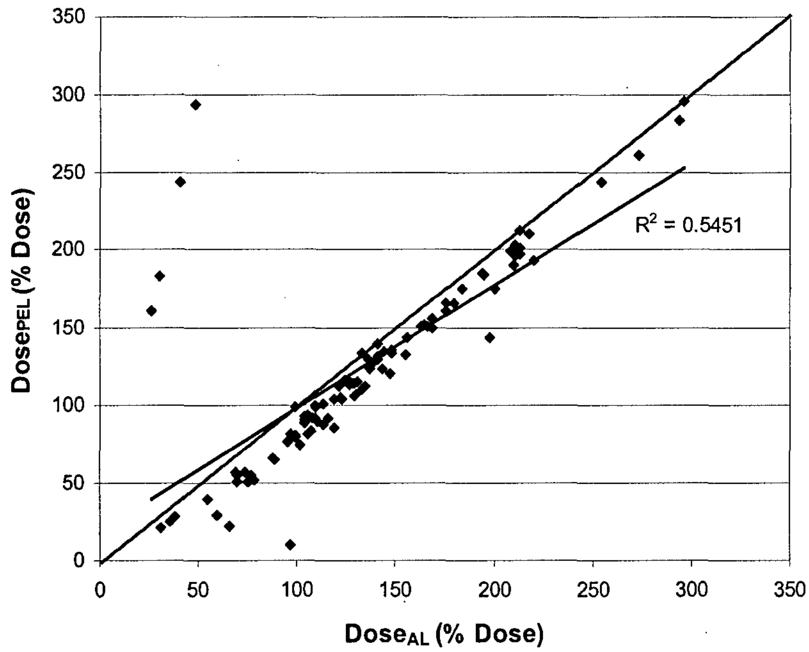

Figure 3. MSHA data comparison of $Dose_{AL}$ and $Dose_{PEL}$

The difference between $Dose_{AL}$ and $Dose_{PEL}$ ($Dose_{AL} - Dose_{PEL}$) are plotted in Figure 4. The four negative points are the same impossible data points from Figure 3. There are also two data points that indicate a difference of more than +50%, which makes them highly suspect. If the four impossible points and the two highly suspect points are removed from the data set, the R^2 for the linear regression line through the correlated data changes from 0.5451 (Figure 3) to the 0.9844 value shown in Figure 5. An R^2 this high should be expected in this type of data set where the measurements are taken by the same instrument of the same exposure and much of the exposure is above the 90 dBA threshold of the $Dose_{PEL}$ reading.

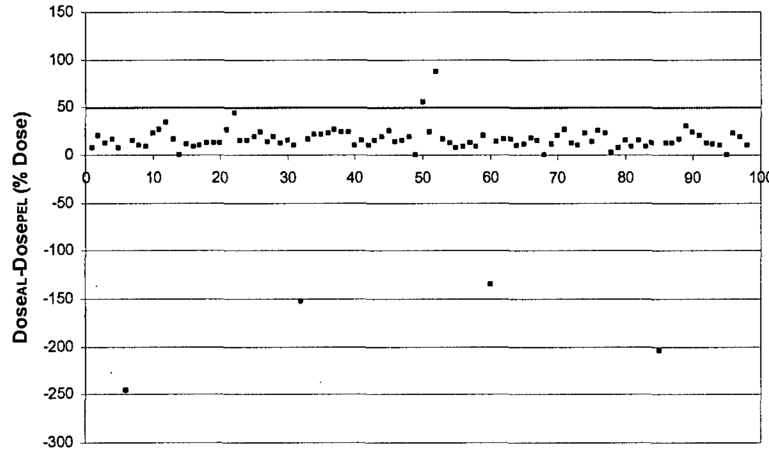

Figure 4. Difference between Dose$_{AL}$ and Dose$_{PEL}$

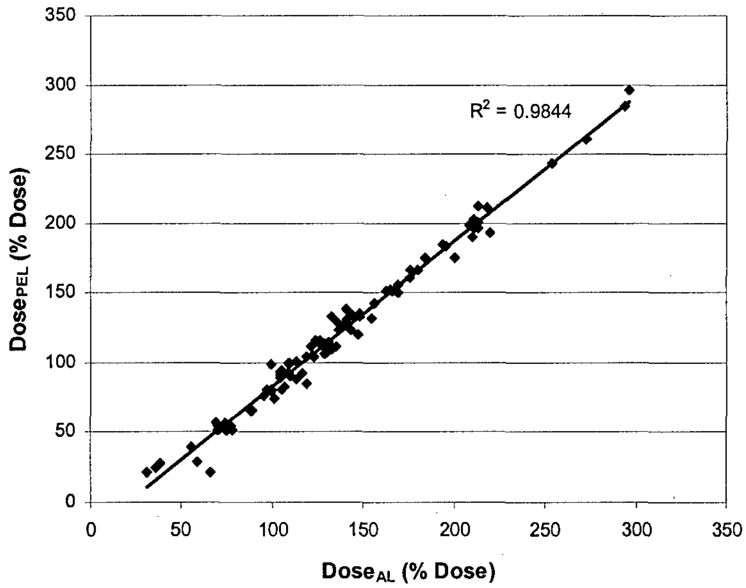

Figure 5. Correlation of scrubbed MSHA data

It should be emphasized, however, that data should not be excluded simply because it doesn't fit expectations. Often the most interesting and revealing data are the outliers. Those unexpected data points that are valid lead to discoveries about the underlying processes being sampled. The purpose of this article is to give methods to validate dosimetry data, and if necessary, justify the exclusion of erroneous data. In this case, the data were either impossible or highly unlikely. Also, the widespread jurisdiction of MSHA requires that many different inspectors perform the measurements, under less than desirable environmental conditions, all feeding into a common database. Human error is almost inevitable and these methods offer assistance in correcting that error.

Using these same methods to validate the entire MSHA database (n = 577) led to the following results:

Table 4. Error rate from entire MSHA dosimetry database

DoseAL – DosePEL (%)	n	Judgment
< 0	8	8 impossible
= 0	8	5 incorrect, 3 questionable
> 50	11	11 unlikely
	Certainly in error	13 (2.3%)
	Probably in error	27 (4.7%)

This is not an enormous error rate given the size of the data set, however these errors were easily removed using the techniques explained.

Corroborating With Concurrent Survey Information

A simple technique to estimate miner dose that can be accomplished prior to any dosimetry is to estimate dose based on the sound pressure levels (SPLs) of the various noise sources associated with the miner's tasks. The average SPLs of the noise sources in a particular headgate shearer operator's shift are given in Table 5. Note that different occupations would have different exposure durations to these various sources.

Rearranging equation 1, the dose rate per minute for that particular average SPL can be determined by:

$$\frac{Dose}{T} = \frac{100\%}{480x2^{-\left(\frac{SPL-90}{5}\right)}} \qquad \text{1a}$$

The dose rate multiplied by the miner's estimate of time exposed during the individual tasks gives the dose contribution per task during the workshift. The summation is an estimate of dose for a shift, and can be used to corroborate dosimetry results.

Table 5. Dose estimate for a particular headgate shearer operator

Task	Average SPL (dBA)	% Dose rate per minute	Estimated exposure time (min)	Dose estimate per task
Mantrip	89	0.1760	60	11%
Power Station	98	0.6364	2	1%
Headgate	90	0.2160	10	2%
Face conveyor	83	0.0768	30	2%
Shearer, head, not cutting	91	0.2460	45	11%
Shearer, head, cutting	96	0.4859	278	135%
Lunchroom	75	0.0260	45	1%
Shut down	72	0.0172	70	1%
		$\sum$	540	164%

A further utility in such an exercise is that one can quickly confirm the noise sources which most contribute to dose to aid in engineering control prioritization. For instance, although the highest SPL for the headgate shearer operator was generated by the power station (98 dBA), the time of exposure is so short that expending great effort on engineering controls for the power station would have little effect on the noise dose to the headgate shearer operator. Clearly the shearer cutting coal was the highest contributor to dose.

This estimate of dose for the headgate shearer operator falls within the 95% confidence interval on the estimate of the mean dose for the MSHA data of the same occupation (103-166%) using Land's exact method for estimating the confidence limits on the mean.

Corroborating with Production Data

While it is logical that production data would be correlated to noise dose for those occupations most closely linked with the production, such as the shearer operators, there was very little correlation in the data ($R^2 = 0.0933$). Figure 6 shows the correlation between production and $Dose_{AL}$ for the headgate shearer operators in the MSHA data. There is a general upward trend, and it would still be wise to compare the production for that shift with the dosimetry data. If the miner reports wearing the dosimeter and working at his station all shift, and there were 7,395 tons of coal mined during the shift one would expect his dose to be near 150% given other data from the same mine. The actual data point below was associated with a 40% dose for the headgate shearer operator. Conversely, if there were only 459 tons of coal mined that day, the safety and health professional should inquire as to the duties performed during a shift that produced 131% dose. None of this is to say that such observations of dose and production are impossible, it is only to encourage those taking the dosimetry data to question results that do not fit expectations. It is very likely that on a low production day the miners spent their time assisting with the maintenance work needed to get the line back up and running. A reasonable explanation for odd data can only help the interpretation. Further, the investigation of strange outliers often leads to the most interesting discoveries about worker exposures.

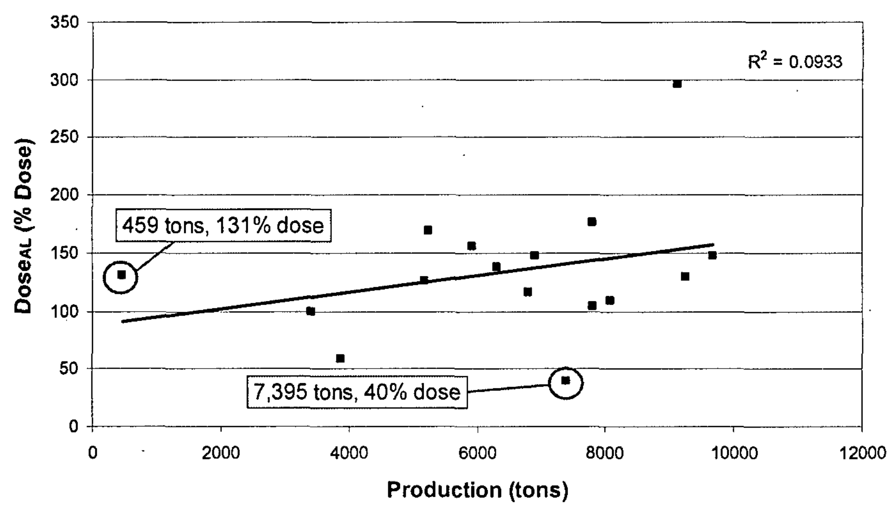

Figure 6. Correlation of headgate shearer operator $Dose_{AL}$ to production

Corroborating with Previous Surveys of the Same Exposures

Very useful for both mine operators and MSHA inspectors is the technique of checking the past exposure measurements from the same mine. Table 6 shows the summary statistics from one mine from the MSHA database. The dose readings were converted to L_{eq} so that the readings would likely follow the standard normal distribution. $Dose_{AL}$ data usually follows the lognormal distribution, so that data was used to generate the geometric mean (GM) and geometric standard deviation (GSD) numbers. The data are presented broken down by occupation, as well as summarized across the mine. The distribution range is the mean ± 1.96 standard deviations. If a dose measurement exceeds the bounds of the 95% range, one's interest would be piqued to inquire as to the circumstances. However, if the measurement was within the bounds, it likely follows the distribution already sampled and is acceptable.

Table 6. Summary statistics from a single mine

Occupation	n	Mean ± std. dev. (dBA)	95% Range Mean ± 1.96 *x* std. dev. (dBA)	GM (%Dose)	GSD
Headgate	10	90.6 ± 2.0	94.5 - 86.7	129.3	1.31
Jacksetter	8	88.8 ± 1.5	91.6 - 85.9	100.2	1.24
TG shearer	9	90.6 ± 2.6	95.8 - 85.4	128.6	1.43
HG shearer	7	93.4 ± 8.2	109.5 - 77.3	123.9	1.30
Overall	34	90.7 ± 4.2	99.0 - 82.4	120.5	1.34

Corroborating with Surveys in Other Mines

The data taken in a particular mine could also be compared to other mines in the same seam with similar equipment. For instance, if one determined to corroborate his data with data from the Pittsburgh seam using a Joy shearer (all models currently in use), the mean L_{eq} for the headgate shearer operator in Table 7 would be 92.1 dBA (Geometric mean dose of 138.7%). If the data collected were more than two standard deviations from the mean (outside of 86 – 98 dBA) then one might question the conditions. However, if the data were within the range, this increases confidence in the decisions made using the data.

Table 7. Summary statistics from mines in the Pittsburgh seam using Joy shearers

Occupation	n	Mean ± std. dev. (dBA)	95% Range Mean ± 1.96 *x* std. dev. (dBA)	GM (%Dose)	GSD
Headgate	33	91.1 ± 3.6	98.2 - 83.9	109.8	2.19
Jacksetter	42	88.6 ± 2.7	93.9 - 83.2	72.1	1.83
TG shearer	28	91.0 ± 2.1	95.0 - 86.9	117.3	1.61
HG shearer	35	92.1 ± 3.1	98.1 - 86.2	138.7	1.64
Overall	138	90.6 ± 3.2	96.9 - 84.2	103.9	1.92

Considering the information gathered by the mine operators in the Appalachian region fitting these criteria, their average was 92.2 dBA L_{eq} (geometric mean dose of 155%) for the headgate shearer operators, with a range of 13 values from 81.0 - 95.8 dBA. Only one measurement from the mine operators fell outside the two standard deviation range of the MSHA data and might be investigated.

Summary

In the end, these methods for increasing data integrity revealed mixed results with respect to the carefully-conducted mine operators' dosimetry study (Table 8). The data validation measures described above led to the exclusion of between 4-7 data points per occupation. The data validation process reduced the variation in data for all but the tailgate shearer operator, which was virtually unchanged (65 vs. 66). The process also decreased the difference between MSHA data and the mine operator's data for the headgate operator and the jacksetter. The tailgate shearer operator average was unchanged. The headgate shearer operator average moved farther from the mine operator data.

Table 8. MSHA pre and post-validation $Dose_{PEL}$ averages by occupation compared to operators' data

	MSHA Raw Data		MSHA Clean Data		Mine Operators	
Occupation	Mean±Std dev.	n	Mean±Std dev.	n	Mean±Std dev.	n
Headgate Operator	150±70	47	138±63	42	131±61	14
Jack Setter	108±47	61	102±45	54	101±46	15
TG Shearer Operator	157±65	49	157±66	45	167±73	14
HG Shearer Operator	134±53	41	124±41	37	175±73	13

The three data sets (MSHA raw, MSHA clean, and Mine Operators) were compared using one-tailed t-tests. Under the null hypothesis that there was no difference between the true means of the data sets (H_0: $\mu_1=\mu_2$), a p-value ≤ 0.05 would indicate that the two data sets are significantly different. As shown in Figure 7, the MSHA raw and the MSHA clean data were not significantly different for any of the occupations. After data validation, the headgate operator and jacksetter data was less significantly different from the mine operators' data. However, the headgate and tailgate shearer operator data became more different from the mine operators' data after validation. Note that only the headgate shearer operator data was significantly different between MSHA and the mine operators.

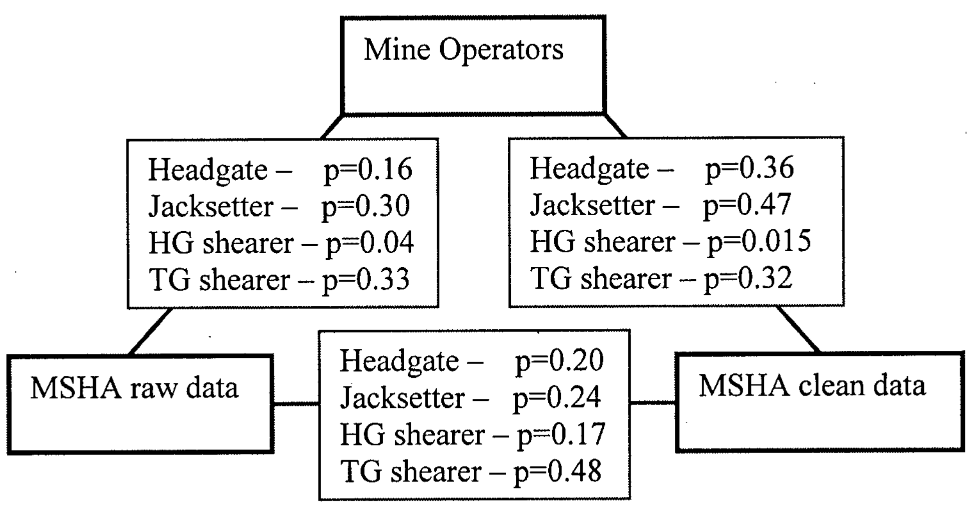

Figure 7. t-test comparisons between data sets by occupation

DISCUSSION

There is no question that average exposure data provides a superior assessment of health risk to chronic illness than one-time grab samples. NIHL is a permanent illness to which miners bear an inequitable burden of risk in the current compliance decision scheme. As was shown, average exposure data gave different decision information than the current scheme in both directions using the sufficient data that MSHA has already collected since the enactment of the new noise rule. It seems reasonable for MSHA and mine operators to consider using average data to determine health risk to NIHL. Note that changes to the noise environment would necessitate restarting the data collection in order to represent the latest risk.

If average exposure were to be used, then historical data become just as important as the data collected on a given day, and data validity is an issue. This paper discussed several ways to check data validity. When a new mine opens, the method of corroboration with surveys in other mines under similar conditions provides a good starting point. Also, the first survey should include concurrent survey information such as sound pressure levels and estimates of exposure duration to estimate dose and compare to dosimetry readings. Production data should be collected at every survey as another piece of information to ensure representative days are sampled. The $Dose_{AL}$ and $Dose_{PEL}$ readings should be compared at the conclusion of the first and every survey to validate the data as it is recorded. As more surveys are conducted at the mine, each survey can be compared to previous readings in the same mine to watch for odd data.

A compliance decision from the MSHA inspector could follow the current scheme until a minimum number of readings for each similar exposure group were completed. Assuming a normal distribution with a standard deviation of 3.7 dBA L_{eq}, the sample size needed to determine the average exposure within ± 3 dBA with 95% confidence would be 6 samples. (Table 9.) A good rule of thumb would be to take several readings on different shifts and apply the current MSHA decision scheme until a minimum number of readings are collected.

Table 9. Required sample size for given 95% confidence interval length on mean L_{eq}

Interval Length	Required n
10 dBA (± 5 dBA)	3
8 dBA (± 4 dBA)	4
6 dBA (± 3 dBA)	6
5 dBA (± 2.5 dBA)	9

MSHA could also incorporate mine operator data into their decision scheme, or use it to corroborate their data.

CONCLUSIONS

This paper has explored a central issue of miners' health with regards to proper compliance enforcement. The suggested methods for compliance assessment may aid operators and inspectors in making better judgments to protect miners' hearing. The procedures to ensure data integrity are simple to employ and can be used regardless of decision scheme employed.

ACKNOWLEDGMENTS

This work was done under NIOSH Grant 1-R01-OH07732. The authors would also like to express gratitude to several MSHA and NIOSH offices, as well as the coal mine operators who graciously supported the efforts.

REFERENCES

MSHA [2001]. Coal Mine Health Inspection Procedures Handbook (PH89-V-1(13)). Mine Safety and Health Administration. Arlington, VA.

MSHA [2004]. Noise Dosimetry Database. Available to the public through any MSHA office. Mine Safety and Health Administration. Arlington, VA.

U.S. Air Force [1994]. Hazardous Noise Program (AFOSH Standard 48-19). Dept. of the Air Force. Washington, DC.